Draft Report

Little Calumet and Portage Burns Waterway TMDL for *E.coli* Bacteria, and Cyanide

Modeling Framework Report

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1. INTRODUCTION

1.1 Study Area

Six stream segments (Figure 1 and Table 1) of the Little Calumet – Portage Burns Waterway are listed on Indiana's Section 303(d) list of impaired waters. Over 51 miles of stream have been classified as being impaired. The parameters of concern for Little Calumet River and Portage Burns Waterway are *Escherichia coli* (*E. coli)* bacteria and cyanide, based on the 1998 - 303(d) list. Little Calumet River is located in the Little Calumet – Galien Watershed (USGS Cataloging Unit 04040001) and Chicago Watershed (USGS Cataloging Unit 07120003). Portage Burns Waterway is located entirely in the Little Calumet – Galien Watershed in Northwest Indiana.

FIGURE 1
STREAM SEGMENTS LITTLE CALUMET RIVER AND PORTAGE BURNS WATERWAY

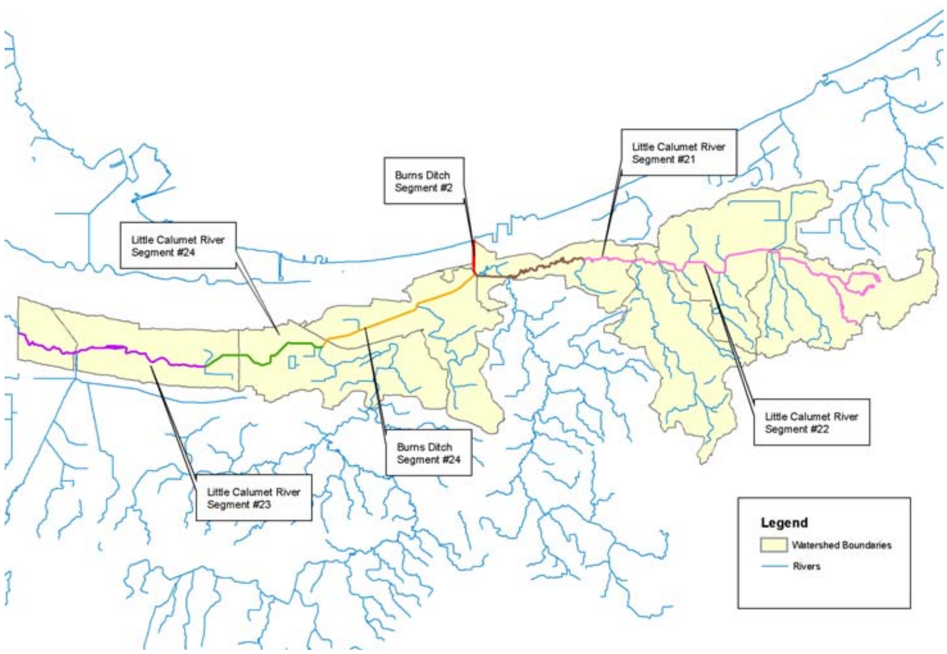


TABLE 1
STUDY REACHES AND PARAMETERS

Water Body	Segment Number	Location	Impairment
Portage Burns Waterway	2	Confluence of East Branch LCR and Burns Ditch North, in Porter County	*E. coli*
Portage Burns Waterway	24	Burns Ditch west to Deep River, just east of I-65 in Porter and Lake Counties	*E. coli*
Little Calumet	21	Confluence of the West Branch of LCR and Burns Ditch east to an unnamed tributary, just west of Hwy 20 in Porter County	*E. coli*
Little Calumet	22	Unnamed tributary east including headwaters of the stream in Porter and LaPorte Counties	*E. coli*
Little Calumet	23	Black Oak to Illinois, in Lake County	Cyanide
Little Calumet	24	Deep River west to Black Oak, between SR 912 and SR 53	*E. coli* & Cyanide

1.2 Purpose

Two previous reports described the data that is available for the development of the TMDL (Earth Tech, 2002) and evaluated the sources of *E. coli* (Earth Tech, 2003) within the watershed. The purposes of this report are to describe:

- The modeling objectives that will be required to develop the TMDLs
- Alternative analytical models considered in developing the proposed modeling approach
- The proposed modeling approach to estimate the loading and load capacity of the appropriate constituent to the corresponding stream segments.
- How the components of the existing pollutant loads will determined distribution among (wasteload allocations (WLAs), load allocations (LAs), natural background, Margin of Safety (MOS) and seasonal variations.

2. MODELING OBJECTIVES

Selection of appropriate analytical tools (computer models) for determining TMDLs for the Little Calumet River and Portage Burns Waterway must consider both technical water quality criteria and general modeling criteria. Selected analytical tools must be capable of simulating the chemical processes of the associated constituents. In addition, analytical tools must be appropriate given the expectations of stakeholders and the availability of information.

2.1 Water Quality Criteria

2.1.1 E. coli

E. coli is found in the intestinal tract of warm-blooded animals, including humans, livestock, domestic pets and wildlife. Their presence is used as an indicator of potential presence of pathogens. They are found in both point source and nonpoint source pollution and are present as free-floating bacterium as well as attached to solids. Their survivability in the environment are affected by a complex combination of physical and chemical factors such as those in Table 2.

TABLE 2
FACTORS AFFECTING BACTERIA SURVIVABILITY

Parameter	Die-off Rate Response
Lower Temperature	positive
Higher Temperature	negative
pH – acid	negative
Organic Matter	positive
Dissolved Solids	positive or negative
Solar Radiation	negative
Nutrients	positive

The physiology of the bacteria can change as one or another factors become limiting for the survivability of the bacteria. This ability to respond to its environment partially explains the recovery of the bacteria population ("after-growth") that is sometimes observed in the field. The model that is most commonly used to describe the behavior of bacteria populations, such as *E. coli*, was first described by Chick in 1908 and is now known as Chick's Law. Chick's Law is a first order reaction represented by the equation:

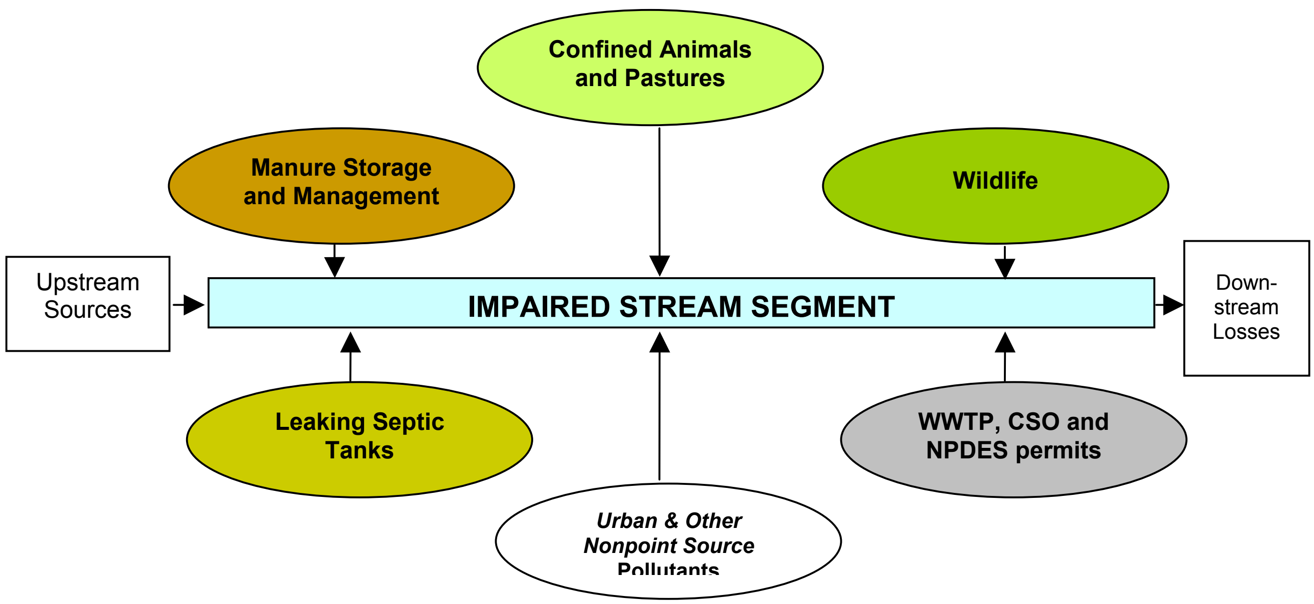
$$\frac{N_t}{N_O} = 10^{-kt}$$

Where:

N_t = number of bacteria at time t
N_O = number of bacteria at time 0
t = time in days
k= first order of die-off rate constant

The equation assumes that die-off begins immediately and continues at a steady rate until the entire population is depleted. The equation has been modified by various researchers (Thomann, Robert V., John A. Mueller. 1987, Chamber and Mitchell, 1978, and Reddy, K, et. al. 1981) to more closely account for the delay in the start of the die-off, variability in the die-off rate constant, affects of temperature, pH, solar radiation and soil moisture. The challenge in predicting the concentrations of bacteria, like *E. coli*, are first to determine the initial concentration (N_O), then determining the transport mechanisms that are involved in moving bacteria from the source - overland to the water body – downstream to the outlet of the study area. The diagram below illustrates the various fate-transport processes that should be factored into the establishment of limits on loadings to meet water quality standards.

FIGURE 2 - *E. coli* TMDL MODEL SIMULATION PROCESSES



2.1.2 Cyanide

Cyanide is a triple bonded nitrogen-carbon compound. It is found in the aquatic environment in both organic and inorganic forms. Different forms of cyanide have different toxicities. It is often used in metal plating and in metal fabrication and is also present in some pesticides. Since the 1950s, iron cyanide compounds have been used as an anti–caking agent for road salt. Some of the common forms that are known to exist in the aquatic environment are:

Cyanide ion: A single free anion CN^- that behaves chemically similar to halide ions (Cl^-, Fl^-, Br^-, and I^-).

Molecular Cyanide: Commonly referred to as hydrogen cyanide or hydrocyanide (HCN). HCN is a gas at temperature above 26^O C and infinitely soluble in water.

Simple Cyanides: Simple cyanides are represented by the formula form $A(CN)_X$, where A is an alkaline earth element or a metal and x is the number of cyanide groups. Simple cyanides are very soluble in water and readily hydrolyze to HCN under normal environmental conditions.

Complex Cyanides: Referred to as metallocyanides, complex cyanides can be represented by the form $A_yM(CN)_X$, where A represents the alkali present y times, M the heavy metal and x is the number of cyanide groups. Dissociation to HCN is largely dependent on pH. Ferro- and ferricyanide and other complexes dissociate to HCN when exposure to sunlight (utraviolate).

Organocyanides: Organocyanides, also called nitriles, are organic compounds containing one or more cyanides groups. They are produced naturally by some plants, such as lima beans, almonds, plums, peaches and pears. Chloroacetonitriles can be produced as a by-product of the cholorination of some wastewater. Nitriles are generally highly volatile and biodegradable.

Cyanates: Cyanates are compounds containing the –OCN group. They are formed when a strong oxidizing agent such as Cl_2 or Br_2 is introduced to an alkaline solution containing free cyanide. Alkaline chlorination is often used to treat wastewaters containing cyanides. Cyanates are less toxic than HCN and are oxidized by chlorine to carbon dioxide and nitrogen gas.

Thiocyanates: Thiocyanates are compounds that contain the –SCN group and are less toxic than HCN.

Cyanide chemistry is complex. Pathways within the aquatic environment include:

- Offgassing as HCN
- Hydrolysis which results in the breaking of the C-N bond
- Sulfidation to thiocyanate
- Precipitation of insoluble cyanmetallic compounds and
- Adsorption on sediments

Cyanide loadings can be classified as either old or new sources. Old sources would include contaminated fill material within the watershed that is leaching cyanide into the stream or in-stream sediment deposits that are contaminated. New sources would include the point sources from municipal or industrial discharges of either sanitary or storm sewers. The specific chemical characteristics of the cyanide determine the mobility of the pollutant and must also be considered. These include:

- What portion of the pollutants are dissolved in the water column versus attached to soil particles
- Water solubility of pollutant– maximum concentration pollutant can reach in stormwater runoff
- Adsorption coefficient of pollutants – the tendency of the pollutant to attach to soil particles
- Half-Life of pollutants - factoring in volatilization, photolysis, hydrolysis, biodegradation and chemical reaction.

2.2 General Modeling Criteria

Three general criteria affecting model selection include **public (stakeholder) acceptance**, **data requirements** of the model and the **accuracy of the model.**

2.2.1 Public (Stakeholder) Acceptance

A successful model should be a predictive and educational tool. Though not all of the intricacies of any particular model may be understood by the general public, stakeholder's comfort that the modeling methodology represents the processes affecting water quality increase the likelihood that the results will be accepted. The public's acceptance that the science behind the TMDL is sound increases the chance of the successful implementation of recommendations.

2.2.2 Data Requirements

A model is only as good as the input used. Appropriate data must be available and is required for:

- Input into the model
- Calibration of the model and
- Validation of the model's predicted results.

Sources of pollution include: wastewater treatment plants, CSOs, septic systems, industrial discharges, animal production units, and land application of animal waste (domestic and wildlife), urban stormwater and "background" conditions. Having enough of the right data to predict the magnitude of the role of each of the source areas is essential. In some cases literature values can take the place of having actual data. However, in other cases there may be too many unknowns to be able to make an educated approximation.

2.2.3 Model Accuracy

Ideally the processes that are needed to describe pollutant sources and their fate-transport through the system that should be factored into the development of the TMDL for the Little Calumet River/Portage Burns Waterway are outlined in the Tables 3, 4 and 5 below. At issue, is the detail to which these processes are accounted for to withstand scrutiny and legal challenges. In addition, questions to be considered when matching a model to a particular TMDL are:

- Does the model have sufficient accuracy to represent these factors?
- Can the model simulate the unique characteristics of these factors, such as seasonal variation and the interaction of pollutant loads?
- Is there data available to meet the model's input requirements?
- Can the model accurately simulate results on the desired temporal requirements (i.e., hourly, daily, monthly, yearly)?

TABLE 3
SOURCE LOADINGS FOR BACTERIA AND CYANIDE

Agriculture Nonpoint Sources
Manure Application
Manure Incorporation
Feed Lot Operation
Point Sources
CSO, SSO and Pipe Outfalls
Other Nonpoint Sources
Urban Runoff and Septic Tanks
Open Land and Rural Runoff

TABLE 4
BACTERIA FATE AND TRANSPORT

Spatial and Temporal Distribution of Point/Nonpoint Sources
Die-off / Re-growth
Transport of Bacteria by runoff
Transport of Bacteria by Sediment Transport
Loss of Bacteria to Soil Infiltration
In-Stream Transport of Bacteria
Routing of Bacteria to Receiving Water
Influence of Temperature on Die-off / Re-growth

TABLE 5
CYANIDE FATE AND TRANSPORT

Spatial and Temporal Distribution of Sources
Volatilization
Soil Adsorption and Sediment Erosion/Transport
Solubility and Wash-off
Decomposition (Photo-, Biological-, Chemical-)
Burial of Pollutants by Sediment Deposition
Deposition/Re-suspension

2.3 Specific Modeling Objectives

Analytical tools that are to be used to develop TMDLs for *E. coli* and cyanide for the Little Calumet River and Portage Burns Waterway will have to be compatible to the basic constraints and assumptions of size and characteristics of the study area, work with the limited data available and still provide the temporal and analytical data necessary to develop the TMDL. These basic constraints and assumptions are summarized in the following sections.

2.3.1 Modeling *E. coli*

Limits of Analysis

The analysis of the existing and allowable loads of E. coli will be limited to the five stream reaches listed blow. The analysis does not include tributary watersheds of Coffee Creek, Salt Creek, Deep River and Hart Ditch.

- **Portage Burns Waterway Stream Segment 2 -** Confluence of East Branch LCR and Burns Ditch North, in Porter County
- **Portage Burns Waterway Stream Segment 24 -** Burns Ditch west to Deep River, just east of I-65 in Porter and Lake Counties
- **Little Calumet Stream Segment 21 -** Confluence of the West Branch of LCR and Burns Ditch east to an unnamed tributary, just west of Hwy 20 in Porter County
- **Little Calumet Stream Segment 22 -** Unnamed tributary east including headwaters of the stream in Porter and LaPorte Counties
- **Little Calumet Stream Segment 24 -** Deep River west to Black Oak, between SR 912 and SR 53

Sources and Source Areas

There are five general pollutant sources that need to be considered in the modeling effort.

- NPDES Discharges (point sources) – assumed to be in steady-state condition based on known data.
- CSO discharges – intermittent discharges based on estimates using known data about the discharge event.
- Urban Nonpoint Sources Stormwater – no known sampling data, however could estimate loads knowing runoff volume and land use.
- Other Nonpoint Sources (such as livestock, wildlife and failing septic tanks) – there is no known data to quantify loads form these sources.
- Loads from Tributary Watersheds (Coffee Creek, Salt Creek, Deep River and Hart Ditch) – loads will have to be approximated using techniques such as estimating loads using regressions from known stations, assuming steady state average conditions and estimating loads using sampling data and estimated streamflow.

Temporal Distribution

In some cases, TMDLs for bacteria have been developed for a certain critical flow condition. There were no apparent patterns to the water quality violations relating to *E. coli* that would suggest that violations were more common during a certain time of year or under some critical flow or weather conditions. Therefore, the TMDL will have to consider a range of climatic and flow conditions. This would favor a model capable of continuous simulation of flow and rainfall.

Parameters

E. coli concentrations will be reported in units of colony forming units per 100 milliliters. Some of the observed data is reported as fecal bacteria. This data will be converted to *E. coli,* where it is needed, using regression equations like those developed by LTI (1999) and Chapman (2001).

End Results

The goal is to estimate the existing bacteria loadings to the waterways that approximate the observed water quality conditions. From these findings, estimates of the contribution of point sources, nonpoint sources and tributary watershed will be determined. This will allow strategies to be developed to reduce loads that will not result in violations of water quality standards.

2.3.2 Modeling Cyanide

Limits of Analysis

The analysis of the existing and allowable loads of cyanide will be limited to the two stream reaches listed below. The analysis does not include tributary watersheds of Deep River and Hart Ditch.

- **Little Calumet Stream Segment 23 -** Black Oak to Illinois, in Lake County
- **Little Calumet Stream Segment 24 -** Deep River west to Black Oak, between SR 912 and SR 53

Sources and Source Areas

There are six general pollutant sources that need to be considered in the modeling effort.

- NPDES Discharges (point sources) – there is no known data indicating the presence of cyanide.
- CSO discharges – there are only a limited number of events from Gary that were shown to contain cyanide.
- CSO discharges – there is no known data for the CSOs from Hammond that have shown the presence of cyanide. This is partially due to the detection limit of the analytical technique used by Hammond that was not able to measure down to the state's water quality standard.
- Urban Nonpoint Sources Stormwater – no known sampling data and would be difficult to estimate loads using computer models without more data to calibrate the model.
- Other Nonpoint Sources (such as groundwater and contaminated sediments) – there is no known data to quantify loads form these sources.
- Loads from Tributary Watersheds (Deep River and Hart Ditch) – there are no known data indicating the presence of cyanide.

Temporal Distribution

In some cases, TMDLs have been developed for a certain critical flow condition. There were no apparent patterns to the water quality violations relating to cyanide that would suggest that violations were more common during a certain time of year or under some critical flow or weather conditions. Therefore, the TMDL will have to consider a range of climatic and flow conditions.

Parameters

Cyanide concentrations will be reported in units of micrograms per liters of total cyanide.

End Results

The goal is to estimate the existing cyanide loadings to the waterways that approximate the observed water quality conditions. From these findings, estimates of the contribution of point sources, nonpoint sources and tributary watershed will be determined. This will allow strategies to be developed to reduce loads that will not result in violations of water quality standards.

3. REVIEW OF ALTERNATIVE MODELS/APPROACHES

There are numerous computer models that could be use to establish TMDLs for the Little Calumet River and Portage Burns Waterway. Typical models that could be used in this analysis are described below. They are classified as either a watershed or water quality models and are arranged from simple to complex.

3.1 Watershed Loading Models

3.1.1 SLAMM

The Source Loading and Management Model (SLAMM) is a fairly simple model for estimating nonpoint source pollutant loads. SLAMM has been developed by Dr. Robert Pitt of the University of Alabama-Birmingham and John Vorhees. SLAMM is based on years of actual field research conducted by Dr. Pitt, the U.S. EPA and other researches. SLAMM simulates the buildup and wash-off process of pollutants that accumulate as a function of land use, amount and type of impervious area, and the time between rain events. Special emphasis has been placed on small storm hydrology and particulate wash-off from source areas within a land use category. Source areas are specific areas such as rooftops, lawns, parking lots, etc. Each source area has unique characteristics that are factored into the accumulation of pollutants that are then carried away by runoff. These factors include connected or disconnected imperviousness, pitched or flat roofs, pavement conditions, type of drainage system and BMPs.

SLAMM has been calibrated using data from all over the United States to simulate pollutants loads for solids, phosphorus, nitrates, TKN, COD, fecal coliform bacteria, chromium, copper, lead and zinc. The model includes data from the early street cleaning and pollutant source identification projects sponsored by the EPA's Storm and Combined Sewer Pollution Control Program (Pitt 1979; Pitt and Bozeman 1982; Pitt 1984), the EPA's Nationwide Urban Runoff Program (NURP) (EPA 1983), as well as studies in the Alameda County, California (Pitt and Shawley 1982), Bellevue, Washington (Pitt and Bissonnette 1984), and the Milwaukee (Bannerman, et al. 1993). SLAMM has been used in many areas of North America and has been shown to accurately predict stormwater flows and pollutant characteristics for a broad range of rains, development characteristics, and control practices. SLAMM is mostly used as a planning tool to better understand sources of urban runoff pollutants. The user is also able to apply a series of control devices (BMPs) to determine how effectively these devices remove pollutants. These features allow SLAMM to incorporate unique processes within a land use category to more accurately predict the sources of runoff pollutants and flows.

3.1.2 GWLF

The Generalized Watershed Loading Functions (GWLF) model was developed at Cornell University to assess the nutrient and sediment loads from a watershed. One advantage of this model is that it was written with the express purpose of requiring no calibration, making extensive use of default parameters. The GWLF model includes rainfall/runoff and erosion and sediment generation components, as well as total and dissolved nitrogen and phosphorus loadings. The current version of this model does not account for loadings of toxics and metals, but with minimal effort improvements can be made to add to this feature. This model uses daily time steps and allows analysis of annual and seasonal time series. The model also uses simple transport routing, based on the delivery ratio concept. In addition, simulation results can be used to identify and rank pollution sources and evaluate basinwide management programs and land use changes.

3.1.3 SWAT

The Soil and Water Assessment Tool (SWAT) was developed by the USDA Agricultural Research Service (ARS). SWAT is a continuous simulation, process-based model. It is designed to predict the long-term impact of land management practices on water, sediment, nutrients, and pesticides in large complex watersheds with varying soils, land use and management. In the latest version of SWAT routines have been added to estimate the growth-die off of bacteria from a source and simulates its fate-transport through watershed to the receiving stream. The routines allow users to simulate two forms of bacteria, persistent and less persistent, to give flexibility during calibration. The model is physically based and uses readily available inputs.

SWAT has its origin in SWRRB (Simulation for Water Resources in Rural Basins) and has since incorporated the soil erosion estimating routines of MUSEL (Modified Universal Soil Loss Equation), the chemical fate and transport routines of CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) and GLEAMS (Groundwater Loading Effects on Agricultural Management Systems), the crop growth and yield routines of EPIC (Erosion-Productivity Impact Calculator), the urban buildup/wash off routines from the U.S. EPA's SWMM (Storm Water Management Model) and the in-stream water quality routines of QUAL2E (Enhanced Stream Water Quality Model, Windows).

3.1.4 HSPF

The Hydrological Simulation Program-FORTRAN (HSPF) was developed jointly by the United States Environmental Protection Agency (U.S EPA) and the United States Geologic Survey (USGS). HSPF simulates the hydrologic and water quality processes in both natural and man-made water systems. HSPF is one of the most comprehensive and flexible models of watershed hydrology and water quality available. However, it is also one of the most complex models, requiring large amounts of data for setup and calibration. It has application in the planning, design, and operation of water resources systems. The model often is based on historical rainfall, which enables the use of probabilistic analysis of the hydrologic and water quality results.

HSPF is able to simulate the continuous, dynamic event, or steady-state behavior of a wide range of chemical and biologic processes including: advection of dissolved material; decay of dissolved material by hydrolysis, oxidation by free radical oxygen, photolysis, volatilization, biodegradation, and/or generalized first-order decay; production of one modeled constituent as a result of decay of another constituent; advection of adsorbed suspended material; deposition and scour of adsorbed material; and adsorption/desorption between dissolved and sediment- associated phases. These can be used to simulate dissolved oxygen, BOD, ammonia, nitrite, nitrate, phosphate, phytoplankton, benthic algae, zooplankton, refractory organics, and pH.

3.2 In-Stream Water Quality Models

3.2.1 Kansas Load Duration Curve Methodology

A simple approach developed by the Kansas Department of Health for determining TMDLs is based on the development of "load duration curves. This is a simple method for comparing observed water quality concentrations to the loads that will meet the established water quality standard (the TMDL). The difference between the observed loads to the loads at meeting the water quality standard is the reduction in pollutant load that is necessary in order to achieve the TMDL.

There are three steps to the methodology. The first is to develop a flow-duration curve for the monitoring site. A flow-duration curve is the cumulative frequency of the historical daily flows. It represents the frequency that a given flow is exceeded. The second step is to multiply each of the daily flows by the water quality standard to create a daily load-duration curve. This is a reference line of the allowable average daily loads (cfus/day) for any given flow that would result in in-stream water quality just meet the water quality standard. Lastly, the observed pollutant concentrations are multiplied by the measured flow for that day. The "observed daily loads" are plotted on the same graph as the load-duration curve. Like the flow-duration curve, the load duration curve represents the frequency that water quality standards are or are not being met. Observed daily loads are compared to a daily pollutant load that just meets the water quality standard for the same discharge. The difference between the observed daily load to the reference daily load indicates the reduction in pollution required to meet water quality standard, if the observed daily load is greater than the reference daily load. However if the daily load is below the reference daily load, the difference represents the additional pollutant load that the system can assimilate and still meet water quality standards.

This approach helps to distinguish whether pollutant loads are from point sources or nonpoint sources. Loads that plot above the curve and in the region of exceedance of between 85 and 100 percent of days indicate a steady-input source, which often translates into the indication that the exceedance is the result of a point source. Loads that plot in the region between 10 and 70 percent suggest the presence of storm-driven source contributions, typically nonpoint sources of pollution. A combination of both storm-driven and steady-input sources occurs in the transition zone between 70 and 85 percent.

There are two major weaknesses of this approach. First, it does not factor in the fate and transport of pollutants. It assumes simple dilution of the pollutant in the estimated volume of water. Second, it does not distinguish between sources of pollutants. Though the method can imply that pollutant loads are dominated by point or nonpoint sources, it does not distinguish to contribution from any single source. Estimation of the contribution of a particular source, such as a point source discharge, has to be done as a separate computation.

3.2.2 QUAL2E

The Enhanced Stream Water Quality Model (QUAL2E) is applicable to well mixed, dendritic streams. QUAL2E is a one-dimensional steady-flow, steady state model. It uses a classical implicit backward difference method. It simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance. It can predict up to fifteen water quality constituent concentrations. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources.

By operating the model dynamically, the user can study diurnal dissolved oxygen variations and algal growth. However, the effects of dynamic forcing functions, such as headwater flows or point source loads, cannot be modeled with QUAL2E. QUAL2EU is an enhancement allowing users to perform three types of uncertainty analyses: sensitivity analysis, first order error analysis, and Monte Carlo simulation. The QUAL2E Windows interface was developed to make the model more user friendly. It provides input screens to facilitate preparing model inputs and executing the model. It also has help screens and provides graphical viewing of input data and model results.

3.2.3 WASP

The Water Quality Analysis Simulation Program (WASP) is a generalized framework for modeling contaminant fate and transport in surface waters developed by the U.S. EPA. WASP is based on the flexible compartment modeling approach. It can be applied in one-, two- or three-dimensions for either a single event or continuous time series. WASP simulates the transport and transformation of pollutants including temperature, salinity, pathogens, DO-BOD, nitrogen, phosphorus, eutrophication. DYNHYD is a hydrodynamic model that simulates the movement and interaction of pollutants with the water column. Hydrodynamic parameters generated by WASP are then used in the WASP model.

Problems studied using WASP framework include biochemical oxygen demand and dissolved oxygen dynamics, nitrogen cycle, phosphorus cycle, first order decay, net resuspension/deposition, oxidation, eutrophication, organic chemical and heavy metal contamination. Two WASP models are provided: Toxics (TOXI5) combines kinetic structure with WASP transport structure and simple sediment balance algorithms to predict dissolved and sorbed chemical concentrations in the bed and overlying waters. Dissolved oxygen /eutrophication model (EUTRO5) combines kinetic structure with WASP5 transport structure to predict DO and phytoplankton dynamics affected by nutrients and organic material.

3.2.4 MIKE

The MIKE system is an engineering software package developed by the Danish Hydraulic Institute for modeling and simulation of flows, hydraulics, water quality and sediment transport in streams, rivers, irrigation systems, channels, reservoirs, estuaries, bays, coastal areas and seas. The model system is divided into three software groups; MIKE 11 (the 1-dimensional model), MIKE 21 (the 2-dimensional model) and MIKE 3 (the 3-dimensional model). The model can be applied to branched and looped networks and quasi 2-dimensional flow simulations on flood plains. The computational scheme is applicable to vertically homogeneous flow conditions ranging from steep river flows to tidally influenced estuaries. Both sub-critical and supercritical flow can be described by means of numerical schemes, which adapt according to the local flow conditions. Different modules are available to choose from depending upon the nature of the problem: advection-dispersion module (AD), particle module (PA), water quality module (WQ), eutrophication module (EU), xenobiotics module (XE) including heavy metals, pesticides, PAH etc., mud transport module (MT), Sediment transport (ST), spill analysis module (SA) including oil spill, and 5 different wave modules. All of the models can be set-up to hind-cast, now-cast or forecast depending of the problem and data availability. Also, various degrees of implementing the models can be assessed; from simple set-up using experience and literature as the main data source to very complex set-up implementing data assimilation.

4. MODEL EVAVLUATION

4.1 Assessment of Models for *E. coli*

Developing an analytical model to support the TMDLs for the Little Calumet River Portage Burns Waterway presents several unique challenges. First, is the unique behavior of *E. coli* bacteria from source to ultimate destination. It is generally accepted that die-off of *E. coli* follows a first order decay function (Thomann, Robert V., John A. Mueller. 1987). However, under certain environmental conditions (such as temperature, sunlight, availability of nutrients, etc) the die-off rate changes and can even result in an increase in the number of bacteria (re-growth) (Thomann, Robert V., John A. Mueller. 1987). Further research is still needed to develop an understanding of the impact of these factors before they can be incorporated into a predictive model. Second, there are numerous sources *E. coli*. Any warm-blooded animal is a potential pollutant source including humans, domesticated animals, or wildlife. Third, the process by which bacteria moves from a source, across the landscape to a receiving stream is complex. This fate-transport process varies depending on the source of contamination. Based on our analysis of the available models (described previously) this process is best represented in the routines in the SWAT model but is non-existent in GWLF. Lastly, there are four major tributaries, Coffee Creek, Salt Creek, Deep River and Hart Ditch, which are not included in the study area. Each may contributes significant pollutant loads to the water bodies of interest in this TMDL project. Boundary conditions will have to be established that describes the hydrologic and water quality characteristics of these flows to the Little Calumet River and Portage Burns Waterway.

The appropriateness of using the following models for the development of the *E. coli* TMDL is discussed below.

4.1.1 Watershed Loading Models

SLAMM has been calibrated for bacteria and is fairly simple to use. However, it calibrated to urban areas and is not suitable for large undeveloped areas or agriculture operations. Therefore, SLAMM could only be applied to only the portion of the watershed that is urbanized and is not recommended for use.

GWLF is one of a number of a fairly simple watershed models, but is design to only simulate sediment and nutrients (N, P, and organic C) loadings. An additional step would have to be applied to estimate pollutant loads of *E coli*. The step would estimate *E coli* loads using the runoff volumes estimated by GWLF and an assumed concentration or unit area load. This is an over simplification of the many fate-transport processes found in the study area and is therefore not recommended.

SWAT has the most sophisticated routines for simulating the fate and transport of bacteria. The routines are best suited for rural and agricultural watershed, but can be adjusted for urban areas. However, there is insufficient information as to which sources and which processes need to be simulated. SWAT provides a level of complexity for which there is not sufficient information to support without an extensive and detailed inventory of the various potential bacteria sources throughout the watershed, and outside of the project area. Therefore, SWAT is not a recommended model.

HSPF is also a highly sophisticated and flexible model. But like SWAT, HSPF provides a level of complexity for which there is not sufficient information to support. Therefore, HSPF is not a recommended model.

4.1.2 In-Stream Water Quality Models

Kansas Load Duration Curve Methodology is a very simple tool for developing TMDLs. However, it does not distinguish between sources of pollutants. Application of this methodology may help in establishing a “maximum load", but the tool does not allow for the various potential sources to be identified. In addition, the methodology does not take into consideration the die-off of bacteria as it moves through the system. Therefore, the Kansas Load Duration Curve Method is not recommended.

QUAL2E can account for the die-off of bacteria and could be used to establish a TMDL for *E. coli*. However, QUAL2E is a steady state model, which would be suitable if there was an identified "critical" flow condition around which the TMDL would be developed. However, sampling results indicate that water quality standards are exceeded throughout the year over the whole range of flow conditions. Therefore, QUAL2E is not a recommended model.

WASP is an improvement over QUAL2E, in that WASP can simulate a time series of flows and pollutant loads. There is a fair body of data with which to estimate flows and in-stream *E coli* concentrations. Many of the tributaries have or have had stream gages recording flows. IDEM has collected several years of water quality data with which to calibrate the model. With these two data sources an in-stream predictive model could be constructed to represent observed conditions. Therefore, WASP is a recommended model.

The **MIKE** series (MIKE 11, MIKE 21 and MIKE 3) have the same capabilities of QUAL2E and WASP. MIKE would be a good model to use to develop the TMDLs. However, the cost of the software is significant. It would not be justified to use a model such as MIKE when there is an alternative (WASP) that is in the public domain. Therefore, MIKE is not a recommended model

4.2 Assessment of Models for Cyanide

The lack of data in the Little Calumet River presents several challenges to the development of an analytical model to support the cyanide TMDL. The first is that the chemical form of cyanide found during the monitoring periods is unknown. Some forms are highly reactive while others are very stable. It is not feasible to predict the concentration of cyanide when the kinetics of the reactions of the various forms of cyanide are unknown. However, it would be possible to simulate the more stable forms cyanide as a conservative pollutant. Second, there are no known sources of cyanide. There are a number of suspected sources including: industrial discharges, CSO discharge, contaminated sediments and groundwater, but there is no data to suggest what the source of the cyanide that has been measured in IDEM's monitoring program. Lastly, as with the *E. coli* parameter, there are four major tributaries, Coffee Creek, Salt Creek, Deep River and Hart Ditch, which are not included in the study area. It is unknown if these areas contribute to the pollutant loads to the Little Calumet River. Boundary conditions would have to be established that describes the hydrologic and water quality characteristics of these flows.

The appropriateness of using the following models for the development of the cyanide TMDL is discussed below.

4.2.1 Watershed Loading Models

SLAMM has not been calibrated for cyanide. Therefore, it would be inappropriate to use SLAMM to predict pollutant loads.

GWLF is one of a number of a fairly simple watershed models, but is design to only simulate sediment and nutrients (N, P, and organic C) loadings. An additional step would have to be applied in order to estimate cyanide pollutant loads. The step would estimate loads using the runoff volumes estimated by GWLF and an assumed concentration or unit area load. Unlike many pollutants, cyanide does not show up with any consistency in stormwater runoff. There does not appear to be sufficient volume of data to establish a reliable unit area load. Therefore, GWLF is not a recommended model.

SWAT has some routines for simulating the fate and transport of toxic pollutants. The routines are best suited for rural and agricultural watershed, but can be adjusted for urban areas. However, there is insufficient information as to which sources and which processes need to be simulated for cyanide. SWAT provides a level of complexity for which there is not sufficient information to support. Therefore, SWAT is not a recommended model.

HSPF is also a highly sophisticated and flexible model. But like SWAT, HSPF provides a level of complexity for which there is not sufficient information to support. Therefore, HSPF is not a recommended model.

4.2.2 In-Stream Water Quality Models

Kansas Load Duration Curve Methodology is a very simple tool for developing TMDLs and can be used to demonstrate the reduction in pollutant load needed to meet state water quality standards. It does not distinguish between sources of pollutants, which should not detract from its use since the source of cyanide in unknown. This method can be applied given the limit information available. Therefore, the Kansas Load Duration Curve Method is the recommended model for developing the cyanide TMDL

QUAL2E can simulate the transport of cyanide in the water column. It can also simulate some decomposition/transformation of cyanide. However, the cyanide form occurring in the stream is unknown and therefore cannot be accurately represented. Also, QUAL2E is a steady state model and violations of the state's water quality standard occur over the whole range of flow conditions. Therefore, QUAL2E it would be inappropriate to use to develop the TMDL for cyanide.

WASP is an improvement over QUAL2E, in that WASP can simulate a time series of flows and pollutant loads. However, the cyanide form that occurs in the stream is unknown and therefore cannot be accurately represented. Therefore, WASP is not a recommended model.

The **MIKE** series (MIKE 11, MIKE 21 and MIKE 3) have similar capabilities to QUAL2E and WASP for simulating the chemistry of cyanide. However, it is costly and the sophisticated water quality routines are countered by the lack of data and information to take advantage of them. Again, the same issue regarding the unknown nature of the cyanide form found in the stream is a shortcoming for this model. Therefore, MIKE is not a recommended model.

5. PROPOSED MODELING FRAMEWORK

5.1 Strategy for Modeling *E. coli*

The initial conclusion from the Source Identification and Assessment Report suggested that nonpoint sources were likely more responsible for the violation of water quality standards than were point sources. It is known that nonpoint sources such as urban stormwater, livestock waste, wildlife waste and failing septic tanks are all potential pollutant sources of *E. coli*. However, there was very little information to quantify the contribution of the various nonpoint sources with any degree of certainty.

Therefore, an iterative approach is proposed to develop the TMDL for *E. coli*. The first iteration will be to develop a model that will estimate the loads that result in the observed water quality conditions. Subtracting loads associated with point sources and CSO discharges from the modeled value will provide an indication of the loads associated with nonpoint pollution sources. Given the magnitude from nonpoint source loads and the land use characteristics of the watershed, more reasonable conclusions can then be made as to the possible contribution from the various potential sources.

There is a reasonable body of record data to estimate flows and in-stream concentrations of *E. coli*. Many of the tributaries have or have had stream gages. IDEM has collected several years of water quality data with which to calibrate the model. With the existing flow and water quality data an in-stream model can be constructed that represent observed conditions.

The WASP model is proposed to be used for the development of the TMDLs for *E. coli*. WASP is able to simulate a historical series of flows and observed water quality conditions. This will allow us to quantify the watershed loadings necessary over a range of conditions to result in the observed *E. coli* levels.

5.2 Strategy for Modeling Cyanide

The initial conclusion from the Source Identification and Assessment Report was that there is no data with which one can identify the source of the cyanide contamination. Therefore, it is proposed that the Kansas Load Duration Curve Method be used to develop the TMDL for cyanide. In addition, a water quality monitoring strategy will be developed, in cooperation with IDEM that will help to systematically identify the source(s) of the cyanide. Possible sources include a point source that is not monitoring for the presence of cyanide, CSO discharges, contaminated ground water and contaminated sediments.

6. STAKEHOLDER INPUT

A watershed stakeholder meeting will be held to present the selected modeling approach, approved by IDEM. Comments from the stakeholders regarding the *Modeling Framework Report* will be compiled, reviewed and taken into consideration when developing the models for the Little Calumet River and Portage Burns Waterway. Results of the modeling summarized in the Allocation Report will be presented to stakeholders in a meeting where the draft TMDL will be introduced. Stakeholder comment will be reviewed and incorporated in the final TMDL Report, if appropriate.

7. REFERENCES

Bannerman, R. T., D. W. Owens, and R. B. Dobbs. 1993, Sources of Pollution in Wisconsin Stormwater. *Water Science & Technolog*y. 28, (3/5): 241-259.

Chamber, C. and R. Mitchell, 1978. A Decay Model for Enteric Bacteria in Natural Waters, R. Mitchell (ed.), Water Pollution Microbiology, Vol. 2, John Wiley and Sons, New York.

Chapman, Keith, 2001. Issue Paper for Municipal POTWs and Stormwater Agencies. City of Salem, OR.

Earth Tech, 2002. Data Report, Little Calumet and Burns Ditch TMDL for *E.coli* Bacteria, Dissolved Oxygen, Cyanide, and Pesticides.

Earth Tech, 2003. Source Identification and Assessment Report, Little Calumet and Portage Burns Waterway TMDL for *E.coli* Bacteria, and Cyanide.

LTI, 1999. Lower Geddes Pond TMDL Development Approaches. Limno-Tech, Inc.

Pitt, R., 1979. *Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices*, EPA-600/2-79-161, U.S. Environmental Protection Agency, Cincinnati, Ohio. 270 pgs.

Pitt, R. and M. Bozeman, 1982. *Sources of Urban Runoff Pollution and Its Effects on an Urban Creek,* EPA-600/S2-82-090, PB 83-111-021. U.S. Environmental Protection Agency, Cincinnati, Ohio. 142 pgs.

Pitt, R. and G. Shawley, 1982. *A Demonstration of Non-Point Source Pollution Management on Castro Valley Creek*. Alameda County Flood Control and Water Conservation District and the U.S. Environmental Protection Agency Water Planning Division (Nationwide Urban Runoff Program). Washington, D.C. June 1982.

Pitt, R. and P. Bissonnette, 1984. *Bellevue Urban Runoff Program Summary Report*, U.S. Environmental Protection Agency, Water Planning Division. PB84 237213. Washington, D.C. 173 pgs.

Reddy, K., R Khaleel and M. Overcash, 1981. Behavior and Transport of Microbial Pathogens and Indicator Organisms in Soils Treated with Organic Wastes, Environmental Quality, Vol. 10, July-September, No. 3

Stiles, T.C. 1999, A Simple Method to Define Bacteria TMDLs in Kansas, Kansas Department of Health and Environment, Topeka, Kansas.

Thomann, Robert V., John A. Mueller. 1987, Principles of Surface Water Quality Modeling Control. Harper Collins Publishers, Inc., New York.

U.S. Environmental Protection Agency, 1983. *Results of National Urban Runoff Program (NURP)*.